BOONTON ELECTRONICS CORPORATION

INSTRUCTION MANUAL

MODEL 71-10A

LOW INDUCTANCE ADAPTER

MP MASTER
MA24725

TABLE OF CONTENTS

		Page
1.1	INTRODUCTION	1
1.2	PURPOSE	1
2.1	INSTALLATION	1
2.2	CONTROLS and ADJUSTMENTS	2
3.1	OPERATING PROCEDURE - INDUCTORS	2
3.2	OPERATING PROCEDURE - MAGNETIC CORES . .	5
4.1	Q OF TEST INDUCTOR	10
5.1	CALIBRATION	11
5.2	COARSE ZERO ADJUSTMENT	11
6.1	Q MEASUREMENTS	13

1.1 INTRODUCTION

The Model 71-10A Low Inductance Adapter makes use of a unique principle of parallel resonance to transform small changes of inductance to increments of capacitance which can be measured on the Boonton Electronics Model 71A or 700A Capacitance/Inductance Meter This change of inductance can result from the addition of an inductor to the measuring circuit, or an increase in the inductance of the measuring circuit owing to the introduction of a magnetic toroidal sample into a single turn demountable loop.

1.2 PURPOSE

The Model 71-10A was designed to permit the measurement of small values of self-inductance such as exists in switches, connectors, sockets, printed circuit boards, short cables, etc. Three binding posts and a shorting link are provided. The shorting link is included for both the zeroing operation and the measurement of the unknown inductor, hence its value need not be known.

Two demountable loops are available for the measurement and evaluation of magnetic toroidal cores. One loop is in the normal test circuit and, when encompassed by a core, the increase of inductance is a function of its initial relative permeability. A second loop, located in a network which balances the test circuit, may be equipped with a sample core of known characteristics to expand the sensitivity of the measurement by differential techniques.

2.1 INSTALLATION

Only three interconnections are required between the 71-10A and the 71A (or 700A). The three cables attached to the 71-10A are marked LO TEST, LO DIFF, and Hi. They should be connected to the appropriate terminals of the 71A (or 700A). The HI cable may be connected to either HI terminal on the instrument.

2.2 CONTROLS and ADJUSTMENTS

a. 71A/700A: Connect the 71-10A Adapter to the instrument, as described in 2.1, and turn the instrument on.

1. Set the C/L function switch to C.
2. Set the RANGE pF/μH switch to the 10 pF range position.

b. 71-10A: Before proceeding, be sure that the demountable loops are firmly in place and the shorting link is in the ZERO position.

1. Adjust the ZERO control for a reading of 50 to 75 per cent of full-scale.
2. Adjust the COMP ADJ control on the 71A/700A for a maximum reading. The change should only be a few per cent of full-scale.
3. Adjust the ZERO control for a reading of zero on the meter. The final few per cent may be adjusted with the ZERO control on the instrument.
4. Depress the CAL button and adjust the CAL control for a full-scale reading.

3.1 OPERATING PROCEDURE - INDUCTORS

a. Direct Measurements at the Binding Posts:

Many components having suitable connecting lugs or wires may be measured directly at the binding posts. The shorting link must be shifted to the TEST position and the test device connected between the terminals designated L_x. Connecting techniques should simulate actual conditions of use as closely as possible.

With the unknown inductor connected, the meter will read the value directly, applying the appropriate multiplier, i.e. using a 71-10A/100 (100 nH, f.s.), a reading of 7 pF on the 10 pF range is equivalent to 70 nanohenries.

b. Remote Measurements:

The circuitry of the 71-10A Low Inductance Adapter will permit remote measurements of inductance at a limited distance from the L_x terminals. The required connecting cable to extend the measuring plane should be of special construction. It must have low inductance which should be nearly independent of its physical positioning. Provided the inductance of the extending cable is not too great, the Adapter can be zeroed with the cable connected. The use of an extension cable, however, is not error free, but the error is predictable if the cable inductance is known.

It is recommended that the cable inductance be less than the full scale inductance range of the Adapter. This permits the Adapter to be used to measure the inductance of the cable and the error can therefore be calculated. If ignored, however, the error will be small.

71-10A/100 (100 nH)

For remote measurements, the error is:

$$\text{Error} = -(L'/50)\% \qquad (1)$$

Where L' is the extension cable inductance in nanohenries

71-10A/10 (10 nH)

For remote measurements, the error is:

$$\text{Error} = -(L'/15)\% \qquad (2)$$

Where L' is the extension cable inductance in nanohenries

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71-10A/100 (100 nH)

For remote measurements, the error is:

$$\text{Error} = -(L'/30)\% \qquad (1)$$

Where L' is the extension cable inductance in nanohenries

71-10A/10 (10 nH)

For remote measurements, the error is:

$$\text{Error} = -(L'/15)\% \qquad (2)$$

Where L' is the extension cable inductance in nanohenries

Great care should be exercised when making remote measurements with the 71-10A/100. The zeroing of this Adapter is also an important factor in making meaningful measurements. The leads, if juxtaposed, will have less inductance than when spread to make contact with the device to be tested. If the leads are spread for zeroing, however, a strap must be used to join the ends and the inductance of this strap should be known. In general, the connecting zeroing techniques will contribute substantially more error to the measurement than the extension cable, Adapter, or Instrument.

Although an equation for the error for the 71-10A/10 is given above, remote measurements with this Adapter is not recommended, other than for relative measurements.

A recommended cable for this purpose is dual colored Litz wire. The strands can be segregated at both ends to form a two conductor cable and the intimate coupling provides minimum series inductance for a given length. The effect of the attendant high capacitance is negligible across test specimens of such low impedance.

EXAMPLE: A length of Dual Litz wire, red 10/34, natural 10/34, poly, single nylon, 18 inches long measures 25 nH. With this extension cable connected, the 71-10A/100 Adapter is re-zeroed and calibrated. A specimen connected at the remote end reads 70 nH. Assuming the connection error at the remote end is small, the error owing to the cable will be:

$$\text{Error} = -25/50\% = -0.5\%$$

Thus, the correct inductance of the test specimen is:

$$70(0.995) = 69.65 \text{ nH}$$

If an exceptionally long extension cable is required for a special test, the ZERO control on the 71-10A may have insufficient range to adjust the reading to zero. If this condition occurs, Adjustment #1 on the base of the Adapter may be used for a coarse zero control. Care should be taken not to change Adjustment #2 or else both adjustments will have to be reset according to Section 4.2.

3.2 OPERATING PROCEDURE — MAGNETIC CORES

Danielson and Harrington have suggested* a means of reducing the errors usually associated with the measurement of the initial permeability of toroidal cores. A study of many measurements showed the errors to be largely independent of the permeability. The authors experimentally demonstrated that, using their technique, good accuracy obtained for measurements of low permeability cores using only a few turns. It was further shown that spacing between the core sample and the wire improved the results.

The 71-10A permits permeability measurements using a single turn demountable loop.

The equation which permits using a reduced number of turns was developed by Danielson and Harrington, as follows:

Consider the following two equations which are in general use for the measurement of permeability.

$$\mu' = L_m/L_c \qquad (1)$$

or,

$$\mu' = L_m/L_o \qquad (2)$$

*"A Technique for Reducing Errors in Permeability Measurements with Coils" B.L. Danielson and R.D. Harrington, Proc. of IRE, Vol. 48, No. 3; March 1960; pp 365-366.

where

μ' = real part of the relative initial complex permeability.

L_m = measured inductance in the presence of the core.

L_c = calculated inductance of an equivalent air core inductor assuming a thin uniform current sheet.

L_o = measured inductance of an identical inductor in air, or on a polystyrene core.

If we let ΔL be the error in the measured values of L_m and L_o, and because ΔL is nearly independent of permeability, we can write for the correct values of L_m and L_o:

$$L_m = \mu' L_c + \Delta L \qquad (3)$$

and

$$L_o = L_c + \Delta L \qquad (4)$$

Subtracting (4) from (3) yields an expression for μ' which agrees remarkably well with experimental measurements.

$$\mu' = \frac{L_m - L_o}{L_c} + 1 \qquad (5)$$

The Boonton Electronics Model 71-10A Series of Adapters for ultra-low inductance measurements have demountable loops which are zeroed in the initial adjustment of the adapter. This reduces (5) to:

$$\mu' = (L_m/L_c) + 1 \qquad (5a)$$

L_c is calculated with the usual equation for a toroidal inductor, remembering that $n^2 = 1$ (single turn loop).

$$L_c = 11.7h \log_{10} (d_2/d_1) \quad \text{nanohenries}$$

where

h = height of core (inches)

d_1 = inside diameter of core

d_2 = outside diameter of core

Example: A core with a single turn loop measured 1.6 nH. The dimensions of the core were $h = 0.065"$, $d_1 = 0.078"$, and $d_2 = 0.160"$. The calculated inductance was,

$$L_c = 11.7 \times 0.065 \times 0.3119 = 0.2372 \text{ nH}$$

From (5a)

$$\mu' = (1.6/0.2372) + 1 = 7.75$$

The same core was then wound with 30 turns of number 34 wire and was then measured as,

$$L_m = 1.65 \mu H$$

The calculated inductance, $L_c = 30^2 \times 0.2372 = 213.5$ nH. An identical coil wound on a non-magnetic core measured 265 nH. Subtracting 15 nH (estimated from a nomograph) for the connecting leads, $L_o = 250$ nH. From (5),

$$\mu' = \frac{1650 - 250}{213.5} + 1 = 7.56$$

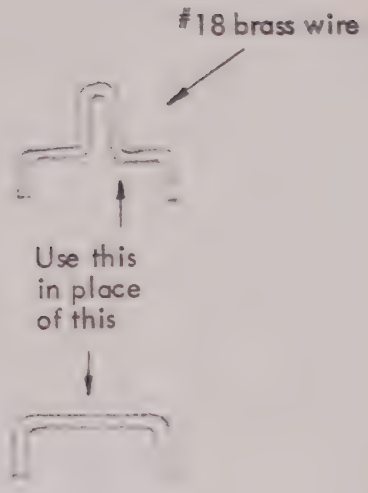
The agreement is within 2.5%.

A second demountable loop is provided in the balancing circuit for improving the measuring resolution by differential techniques, using a core of known permeability installed in the STD loop.

Thus, cores with permeabilities sufficiently high to normally produce off-scale readings, may be compared with a core of known permeability which can be installed in the STD loop. Because these measurements are relative, an instrument range, other than 10 pF, may be used to yield suitable on-scale readings.

For production testing we recommend an external fixture with a lever actuated demountable loop. The arrangement described in 3.1.b. applies.

A simple technique may be employed for the rapid comparison of low permeability cores by substituting a small hair-pin loop for the demountable TEST loop. The approximate configuration is shown here. After rezeroing and calibrating, the test cores are placed over the loop and relative readings may be observed on the 71A or 700A.



This method is suitable for low permeability materials, but cores of higher permeability will increase the coefficient of coupling to the point where the resolution of high values of permeability will suffer. This can be seen by the following analysis:

$$L_t = L_1 + L_2 - 2M$$

and $M = k\sqrt{L_1 L_2}$

if $L_1 = L_2$ (very nearly),

then $M = kL_1$

If the core is symmetrically mounted over the loop (the outer dimension of the loop should be slightly smaller than the inside diameter of the test cores), L_1 and L_2 will be equally increased, i.e.

$$L_1' = nL_1$$

and $L_2' = nL_2$

thus, $L_t' = L_1' + L_2' - 2M'$

where $M' = k'L_1'$

where n is related (but not equal) to the permeability, and the prime (') refers to the new values of L_1, L_2, and M, owing to the presence of the core.

We can rearrange these equations to show that,

$$L_t'/L_t = n\frac{1 - k'}{1 - k}$$

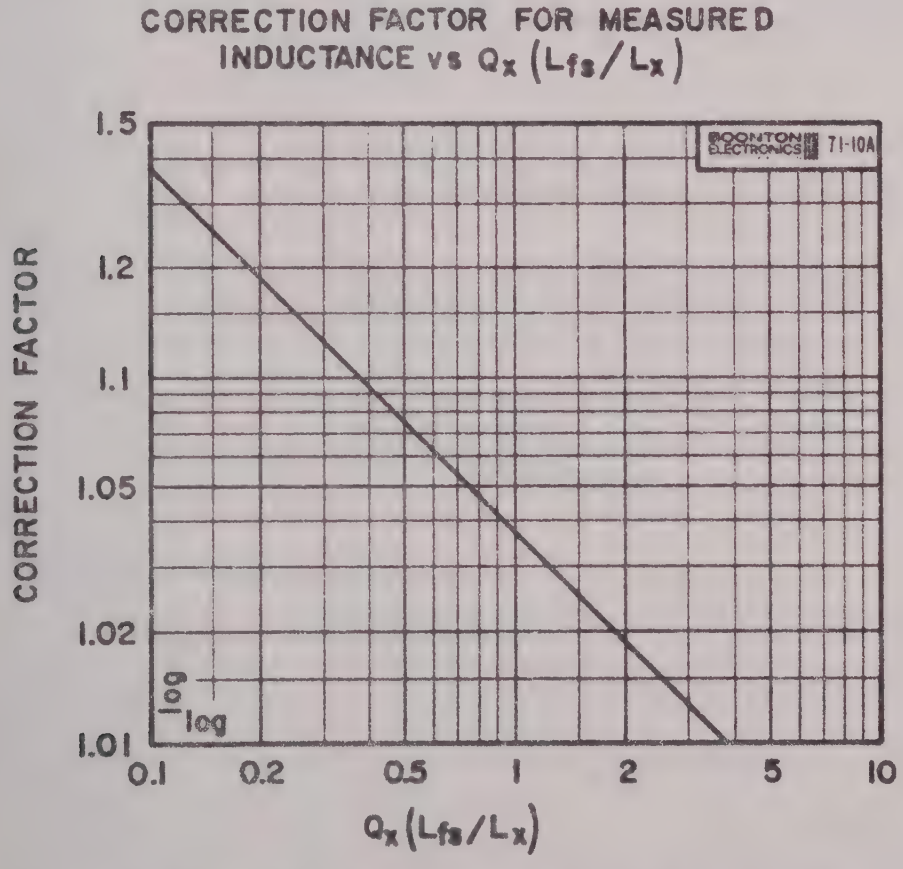
Because of the core, k' is greater than k, and the ratio of L_t'/L_t will increase asymptotically for a linear increase of n. This precludes the use of such loops for high, or even moderately high permeability cores. The method is quite suitable, however, for low permeability ferrite and powdered iron cores.

4.1 Q OF TEST INDUCTOR

Inductors with values of less than 1 microhenry are sometimes low Q devices at 1 MHz. It is important, therefore, to know the influence of the Q of the test specimen on the accuracy of the inductance measurement. It can be shown that the full-scale error is $100/(26Q_x + 1)\%$. It is proportionately less for smaller values of L_x.

Q_x can be approximated using equations which account for skin effect. The Q of the test specimen may also be measured using a 71-10A Adapter in conjunction with a Boonton Electronics 1 MHz three-terminal Capacitance Bridge (see Section 6.1).

Having estimated Q_x (or R_x), a simple correction for the inductance reading is given below.



Example: An inductor with an estimated Q of 0.3 reads 40 nH on a 71-10A/100 Adapter (100 nH f.s.). Entering the abscissa at 0.3 (100/40), or 0.75, the correction factor is 1.05. The value of the inductor is 1.05 x 40 = 42 nH. It is interesting to note that if the estimate of Q_x is in error by 50%, the correction will only change about 2%.

5.1 CALIBRATION

The accuracy of the 71-10A Low Inductance Adapter depends upon the value of the work coil and the calibrating capacitor in the Adapter. The work coil is toroidally wound on a powdered iron core of relatively low permeability and should be electrically stable. The calibrating capacitor is factory set to 25.33 pF and should not require adjustment. If a check is necessary, it can be measured on a Boonton Electronics 1 MHz Capacitance Bridge, Model 75A, 75B, 75D, or 77B.

5.1.1. Zero the Adapter on a 71A or 700A.

5.1.2. Connect the LO TEST and HI cables to corresponding terminals of the bridge and connect the LO DIFF cable to the LO STD terminal of the bridge.

5.1.3. Zero the bridge and then activate the CAL switch on the 71-10A and measure the calibrating capacitance. It should measure 25.33 pF ± 0.5%.

5.1.4. If it does not fall within these limits, it may be recalibrated by removing the base and adjusting the piston capacitor.

NOTE: This capacitor can not be measured on the BEC Model 71A or 700A C/L Meter. For complete calibration, we recommend returning the 71-10A Adapter to Boonton Electronics.

5.2 COARSE ZERO ADJUSTMENT

The two resonant circuits contained in the 71-10A Adapter may occasionally require adjustment to, or near, resonance. Access holes are provided in the base of the Adapter to reach the trimmer capacitors. #1 adjusts the test circuit; #2 adjusts the balancing circuit.

5.2.1. Adjust the ZERO control on the Adapter for a maximum reading on the instrument. If necessary, switch to a higher range on the 71A, or 700A.

5.2.2 Remove the LO DIFF cable from the corresponding instrument terminal.

5.2.3 Adjust trimmer #1 for a meter reading of zero. Set the 71A, or 700A, to the 10 pF range.

5.2.4 Reconnect the LO DIFF cable to the LO DIFF terminal on the instrument and adjust trimmer #2 for a meter reading of zero.

5.2.5 Adjust trimmer #1 for a reading of about 7.5 pF and return the reading to zero using the ZERO control on the Adapter. This completes the coarse zero adjustment. (If, for some reason, a greater positive, or negative, zero range is needed, trimmer #1 can be left in a different position.)

6.1 Q MEASUREMENTS

The Model 71-10A Low Inductance Adapters may also be used with Boonton Electronics Model 75D and 77S three-terminal 1 MHz Capacitance Bridges. The capacitance and conductance readings on the bridge at balance are related to the inductance and Q of the test specimen, but the relationship is not direct.

The following procedure is recommended for the measurement of inductance and Q using a Model 75D or 77S 1 MHz Capacitance Bridge and a Model 71-10A Adapter.

6.1.1 Connect the LO TEST cable of the 71-10A to the LO TEST terminal on the bridge. Leave the other cables free.

6.1.2 Set the Capacitance Bridge range switches to X 0.1 for capacitance and ÷ 1 for conductance. Adjust the TEST LEVEL control to about 1/3 of full output.

6.1.3 Zero balance the bridge.

6.1.4 Connect the HI cable of the 71-10A to the HI TEST terminal on the Capacitance Bridge. Balance the bridge using the CONDUCTANCE dial and the ZERO control on the 71-10A. When balance is nearly complete, the CAPACITANCE dial may be used instead of the ZERO control for final balance. Note the conductance reading, g_o.

6.1.5 Remove the HI cable from the bridge and connect the LO DIFF cable to the LO STD terminal.

6.1.6 Set the DIVIDE G switch to:

÷ 10 for the 71-10A/10

÷ 100 for the 71-10A/100

61.7 Set the CAPACITANCE and CONDUCTANCE dials to zero and turn TEST LEVEL control for full output. Zero balance the bridge using the zeroing controls.

6.1.8 Reconnect the HI cable and balance the bridge with the CONDUCTANCE dial and the ZERO control of the 71-10A. The capacitance dial may be used for the final balance. Read the value of g on the CONDUCTANCE dial.

6.1.9 Using two BNG tee adapters and two UG-1090/U BNC to binding post adapters, connect a film resistor (or deposited carbon) with a value of 1/g (approximately) between the LO and HI STD terminals.

6.1.10 Set the CAPACITANCE and CONDUCTANCE dials to zero and rezero the bridge with the C and G zero controls. The value of the resistor may have to be altered slightly if the range of the ZERO CONDUCTANCE control is insufficient.

6.1.11 Connect the test inductor, or magnetic core to the 71-10A and balance the Capacitance Bridge using the CAPACITANCE and CONDUCTANCE dials. If the CONDUCTANCE dial must be turned toward the red area (negative conductance) for balance, set the C/L switch to L and/or if the conductance reading is low (less than 10% of full scale), set the DIVIDE G switch to the next range and repeat steps 10 and 11. After properly balancing the bridge, note the values of C_x and g_x. The user should understand that these quantities are actually incremental values and as such should be labeled ΔC_x and Δg_x. For convenience, the Δ has been omitted. If the C/L switch is used in the L position, g_x should be assigned a negative sign for the following equations.

6.1.12 The inductance and Q of the test specimen may be derived from:

71-10A/10

$$L_x = 0.3948C_x \quad \text{(nH)} \tag{1}$$

where C_x is in picofarads

and

$$Q_x = 6.283C_x / \left[g_x + 2.5C_x(g_x + g_o) \times 10^{-4} \right] \tag{2}$$

where C_x is in picofarads and g_x and g_o are in micromhos

71-10A/100

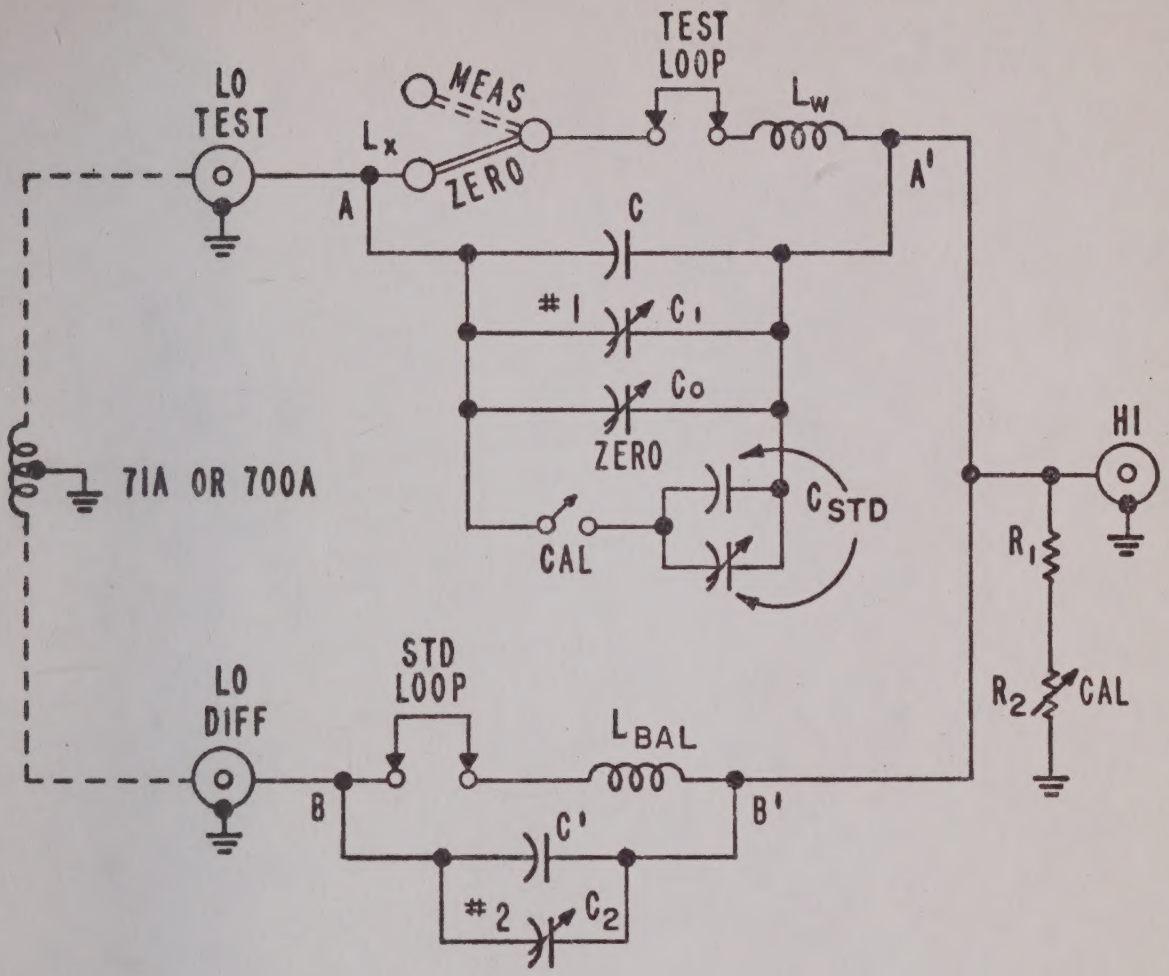
$$L_x = 3.948C_x \quad \text{(nH)} \tag{3}$$

where C_x is in picofarads

and

$$Q_x = 6.283C_x / \left[g_x + 7.9C_x(g_x + g_o) \times 10^{-4} \right] \tag{4}$$

where C_x is in picofarads and g_x and g_o are in micromhos



	71-10A/100	71-10A/10
$C + C_1 + C_o$	2533 pF	8010 pF
$C' + C_2$	2533 pF	8010 pF
C_{STD}	25.33 pF	25.33 pF
L_W (A to A')	10.0 μH	3.16 μH
L_{BAL} (B to B')	10.0 μH	3.16 μH
R_1	300 Ω	300 Ω
R_2	250 Ω	500 Ω

TEST
LOOP
LO
TEST
A
C
ZERO
CAL
STD
LOOP
LO
DIFF
B
TIA OR 7008

MP MASTER
MA24725